Summary of Discussion Sessions
at the
2007 Colloquium on Astrobiology and Mars Exploration

Pasadena, CA
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Introduction

The Colloquium on Astrobiology and Mars Exploration was a one-day event, organized by the Space Studies Board of the National Research Council (NRC) for NASA's Mars Planetary Science Division and Mars Exploration Program, on astrobiology and international planning for the robotic and human exploration of Mars. The Colloquium took place on July 8, 2007, at the Hilton Hotel in Pasadena, California. The purpose of the Colloquium was to bring together robotic and human exploration aspects and U.S.-international aspects of Mars exploration planning in the broad context of the findings of three recent NRC studies in astrobiology science. An agenda is provided in Attachment A.

The Colloquium featured a morning session where NRC study leaders briefed the findings of their reports: *An Astrobiology Strategy for the Exploration of Mars, Exploring Organic Environments in the Solar System,* and *The Limits of Organic Life in Planetary Systems*. These briefings were followed by a status report on NASA planning for exploration of Mars, and time was allocated for questions and answers.

At noon, there was a lunch-time talk by ESA on future planning for ESA's Aurora program. Subsequently, participants broke up into five splinter sessions for further discussion. These splinter sessions focused on the relationships among future Mars missions, including the Mars Science Laboratory, ExoMars, and Astrobiology Field Lab missions; scientific activities foreseen for the human exploration of Mars; exploration of the Martian subsurface; planetary protection for both robotic and human missions; and fundamental issues associated with Mars sample return. The day's activities closed with a short plenary session where splinter groups had the opportunity to describe the principal conclusions of their discussions.

The current report was prepared by student rapporteurs in each session and captures the main topics discussed and widely shared views of participants, but does not necessarily represent the specific views of any individual. An acronym list is attached as Appendix B.

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Session A – Mars Landers (MSL, ExoMars, and AFL)

Co-Chairs: Ed Stolper and Jorge Vago
Organizer: Michael Meyer
Rapporteurs: Nicholas Tosca and Caleb Fassett

The broad goal of the discussion in Group A as established was to lay out the context for upcoming missions, including the Mars Science Laboratory (MSL), ESA ExoMars mission, Astrobiological Field Laboratory (AFL) or Mid-Rovers concept, as well as the connections between these missions. The late-breaking development that a sample caching capability was to be added to the analytical payload of the MSL mission became a major topic of discussion. Preparation for future Mars Sample Return (MSR), as well as characterization, analysis, and caching of samples, is a potential connecting thread between the upcoming, pre-MSR missions.

Mars Caching. There was general agreement that the proposed sample caching effort on MSL faces severe challenges, including the short tactical timeline and additional complexity it adds to the MSL program, the threat to science operations of the MSL rover itself, and major concerns over the sampling strategy and the science return from MSL-cached samples. For example, the nature of geological samples produced and cached by MSL will be composed primarily of fine powders produced by the MSL grinding bits, stored as "samples in a can." As a result of the collection process, fine-scale textural features will not be preserved; moreover, the integrity of volatiles, organic compounds and other labile chemical species contained in the rock sample might be compromised either by the sampling process or from exposure to the harsh Mars surface environment in the ten years between MSL and a MSR mission. Given that the MSL sample-caching effort will not likely represent the most robust and valid step toward sample return, Group A agreed that much more importance should be placed on maximizing the *in-situ* analysis and exploration capabilities of the MSL vehicle per its original design. For example, the presence of a sample cache should not prevent the vehicle from entering craters or other areas that are scientifically rich targets, but not amenable to sample pickup for return to Earth. These complications may prevent the MSL sample caching effort from becoming a robust precursor step toward Mars sample return.

Contribution of Future Missions to MSL. The specific drawbacks of the MSL sample caching led Group A to discuss how future missions, such as AFL, could advance Mars sample return with additional years of planning and technology development. One participant suggested that it is important to conceive of how AFL could maximize both sample return preparation as well as *in situ* analysis. *In situ* capabilities are important to ensure that well-characterized and useful samples are chosen for sample return. Many of the analytical techniques for this purpose that could be deployed on AFL or another precursor-MSR mission might be leveraged from instruments deployed on earlier missions such as MSL and ExoMars. However, one key technology development necessary for AFL or any robust MSR sampling is further improvement in sampling technology, which was described to the Group as a significant challenge for MSL. Other specific desired technologies for AFL or another MSR precursor that builds on MSL and ExoMars include:

1) Precision landing capability;
2) Potential to go somewhere new (other than the site of MSL, ExoMars);
3) Horizontal mobility;
4) Adequate in-situ analysis and characterization, so it can *pick and choose* MSR samples;
5) Full planetary protection certification.
6) Sampling technology that allows key scientific questions to be addressed (volatile and organics preserved; larger samples and in better condition than what would result from drill filing)

It was noted that many requirements for MSR are also important for the future human exploration program; potential synergies exist between the technology and science of MSR and human exploration of Mars.

Defining MSL and "Scientific Success." The discussion of science return and expectations from MSL and its aftermath evolved to define what scientific success would be for these upcoming missions. The Group was concerned that a lack of organic carbon detection by MSL would be viewed by the astrobiology community and by the general public as a possible failure. However, as the expression of life in ancient geologic environments may be textural rather than chemical, more intermediate definitions of success must be presented. Indeed, previous missions have significantly advanced the science community's understanding of habitability of the Martian surface with geochemical and mineralogical evidence, as well as the detailed geological context of the explored landing sites. The Group thought that "Follow the Habitability" was a better goal for mission success than "Follow the Carbon."

Technology Feedforward. Group A believed that success from MSL and ExoMars should be leveraged towards the scientific questions and technology of AFL or other future missions. For example, subsurface access technologies on AFL could build on those of ExoMars, given that ExoMars will have already tested subsurface drilling technology and helped establish the level of scientific return. The Group felt that international cooperation between NASA and ESA on technology is a priority for MSR, both to mitigate costs and to allow international expertise to feed forward to future missions. Samples cached by MSL may have trouble meeting a science floor for a sample return mission, but samples gathered by AFL could handily surpass requirements. There was a broad view that samples cached by AFL could by analyzed, characterized, and preserved in a manner that would far surpass the potential of samples that could be cached by MSL.

Session B – Scientific Activities for the Human Exploration of Mars

Co-Chairs: Pascale Ehrenfreund and Jim Garvin
Organizer: David Smith
Rapporteurs: Doug Archer and Melissa Rice

Necessary Science. Group B assumed that human safety factors, such as the physiological effect of microgravity and the necessary radiation safety precautions, will have been addressed and do not fall under the purview of Mars science.

Discussion suggested that there are no outstanding scientific questions that must be answered prior to human exploration of Mars. The possibility of Martian life, Mars' climate and water history, the fate of Martian organics, and the sources and sinks of Martian methane are all extremely important questions but need not be totally understood before a human mission is launched. It was also felt that future missions already planned as part of the Mars program will have answered, to first order, most of these questions.

Again, though it is not necessary prior to a human mission, Mars Sample Return (MSR) is the highest-priority investigation to be carried out. Retrieving Martian samples and knowing the context from which the samples come, coupled with powerful investigative techniques available in terrestrial labs, will help inform the scientific goals to be addressed as well as which analytical tools that will be needed *in situ* by human explorers on Mars.

Other investigations such as mechanical properties of soil, the near-surface electric and magnetic fields, would be interesting and might inform engineering decisions but are not scientifically necessary before human exploration.

Lessons Learned. The operational experience of past and ongoing robotic Mars missions coupled with the experience of the Apollo program must be used to inform human exploration of Mars. First, much of what you think you know scientifically about the area you have chosen to explore will be wrong. Bringing new tools and new capabilities to a new site or even a previously explored site will invariably lead to new data that will cause you to reevaluate what you think you know.

Second, whatever you think you will accomplish in a given amount of time will always take longer. Plan on the possibility that tasks might take 5 times as long as you expect them to take. On a long duration mission, you will spend a large amount of time maintaining equipment that never had problems on shorter missions. Long duration missions to the Moon and Mars will differ significantly from Apollo experience in this regard.

Third, you will learn that risks that terrified you before you went are not as big a deal as you thought. The best way to avoid too much risk aversion is to critically examine everything you are afraid of and honestly examine the risks. A good question to ask is: are there any clues that you have missed or ignored from past missions or experience that would mitigate some of the risk? Conversely, factors that were not considered problematic could pose unforeseen risks or complications during the mission. This is fundamentally connected with exploration and a reasonable amount of risk must be accepted.

Fourth, the explorers on the ground must be given a lot of independence. There must be margin built into the schedules to allow for investigations that come up in the course of other activities. Serendipity has proven to be the source of some of the biggest discoveries on Mars and the Moon. The best way to support such discoveries is to be willing to discard your plans in favor of something new and better.

Finally, the 40-minute difference between the terrestrial and Martian day creates operational issues. Experience with robotic missions on Mars, as well as terrestrial analog experiments, show that the best way to handle this problem for long duration operations is for people on each planet to keep to their respective times. Explorers on Mars will follow the Martian diurnal cycle, while the support staff on Earth follows the terrestrial cycle. This will necessitate ~3 different Earth shifts that rotate with the time offset. In situations where this is not possible, artificial lighting is the best way to mitigate the negative effects of living a day that your body does not experience. It was also mentioned that the social adaptation is much more difficult than the physiological expectation. It is not reasonable to expect that terrestrial support staff will be able to cut off ties with friends and family during the mission as they work a continually shifting schedule.

Exploration Science. Human exploration will enable a huge leap forward in the scientific exploration of Mars. Exploration is an iterative process where you define your direction based on what you discovered that day. The communication lag between Earth and Mars means that robotic exploration from Earth is and always will be slow because of the long timescale of each iteration. A human presence will cut down the iterative timescale enormously and will allow for much more efficient exploration. The resulting area explored will be much greater and this should be factored into mission design. Conversely, humans are much better at finding and exploring micro-environments which will be incredibly important to the search for life on Mars.

Areas of scientific interest that will be greatly aided by human presence are drilling, trenching, and network science. Investigating the third dimension on Mars (depth) will be much easier for human than robotic explorers and will result in many new discoveries and a better understanding of Mars' history. Network science, such as meteorology and seismology, that is realized by measuring parameters over a large area will be greatly enabled by human explorers. Furthermore, such investigations might be necessary from a safety perspective and thought should be given as to the best ways to accomplish both goals.

Analytical Tools. Like any sample return mission, the mass of samples returned to Earth for analysis is limited. One of the most important roles of humans on Mars will be triage. Therefore, tools that help illuminate which samples have priority for return to earth and which samples can be left on Mars are imperative. We understand that there is a direct relationship between the mass and complexity of an instrument and the accuracy and precision of a measurement and that instruments on Mars will, therefore, not match terrestrial counterparts. Advanced field tools are the first thing that will allow human explorers to identify and gather appropriate samples. In their Martian lab, more complex analytical tools will further illuminate the relative importance of gathered samples.

Group B concluded that isotopic analysis allowing for rough age estimates is the single most important investigation for sample triage.

Session C – Exploration of the Subsurface of Mars

Co-Chairs: Jeff Plaut and Steve Gorevan
Organizer: Bruce Banerdt
Rapporteurs: Kennda Lynch and Leah H. Roach

The Exploration of the Subsurface of Mars splinter session (Group C) brainstormed several issues relating to the requirements for initiating subsurface drilling on Martian landed missions. To facilitate this, the organizer and co-chairs broke the discussion into discrete topics:

1. What depths beneath the surface need to be accessed physically in order to address high priority geological and biological science questions?
2. What is the role of remote sensing in addressing these subsurface science questions?
3. What is importance of deep interior?
4. Is scientific prudent to capture a sample without drilling? Would we recommend a sample return that is not a subsurface sample

What depths beneath the surface need to be accessed physically in order to address high priority geological and biological science questions? To answer this question, it was suggested that to address the science objectives as a function of depth. Table 1 shows the result of this discussion and what science objectives relate to particular depths. Below are the science questions deemed most important by the group

1. What is the composition of the rock/ice/regolith?
2. What are the operating pedogenic processes?
3. Are there rock coatings and what is their composition?
4. Are there organics present? What is the effect of the radiation environment at this depth on the organics? Does the host material affect organic preservation or formation?
5. What is the effect of the radiation environment on the host rock, ice or regolith with depth?
6. What is the thickness of the oxidizing layer? Vertical soil profile (oxidants, temperature, duracrust cohesion).
7. Understanding of soil/lithographic profile
   a. If in regolith, what is the stratigraphic story?
   b. If in permafrost, what is the climate change history?
8. What is the thickness and origin of the ground ice?
9. At what depth is the process that brings the water from 100s of meters to the surface active?
10. What is the geothermal heat flux?
11. Is there an extant biosphere? Is liquid water possible?
12. Start looking for zones of liquid water
13. At this depth, would be probing paleo-biospheres. Could also reach base of Polar Layer Deposit (PLD)
14. Start looking for aquifers sourcing gullies and pockets of liquid water
15. If drilling beneath the permafrost cap, could make an inventory of gases, such as

methane

Table 1. Science Objectives vs. Depth

Depth	*Cumulative Science Questions*	*Tools*
1-10cm	1-4	RAT, wheels, scoops, scrapers, robotic arm, ISAD
10cm-1m	1-5	RAT, wheels, scoops, scrapers,
1+ m	1-7	Drill
10+ m	1-10	Drill
1+ km	1-11	Drill (robotic if ice; human if rock/regolith), could be dedicated drilling mission from this depth on
10+ km	1-12	Drill (robotic if ice; human if rock/regolith)
100+ km	1-15	Drill (robotic if ice; human if rock/regolith)

It should be noted that though there was general agreement on the science questions addressed in the above matrix, there was significant discussion on several topics that warrant emphasis.

If life was present at 10cm depth, it would need to have an active metabolism to repair itself from cosmic radiation and to maintain itself in a dessicating environment. However, 10cm is interesting to consider because there are more sources of energy, such as photosynthesis. At what depth might be it useful to start looking for extant life?

By organics, we mean either fossil or current organic molecules – either abiotic or biotic). Ice might be better than rock for preserving organics because it keeps out the hydrogen peroxide.

There was no agreement about at what depth liquid water would first exist. Hydrostatic pressure and geothermal flux might not be sufficient to have liquid water. But the presence of gullies argues that other processes must be occurring to create liquid water. Are the gullies sourced in subsurface liquid aquifers whose outlet is plugged, or in near surface ice layers that melt during an obliquity or precession cycle? An important dichotomy is icy (poleward) versus dry (equator-ward), not northern versus southern. Icy is modern, while dry is integrated history. There is a potential for liquid water in northern plains due to climate variation. How deep do you have to go to get at sediments that were put down in the liquid water conditions of the recent past? That determines how deep drilling would be required.

What is the role of remote sensing in addressing these subsurface science questions?

The Group discussed the various methods of remote sensing that might be applied to address questions of subsurface science. The following table presents a matrix of techniques versus sensing platform location.

Table 2. Techniques versus Platform Location

TECHNIQUE	ORBITAL	AERIAL	SURFACE
Radar			
HF Imaging SAR MHz-GHz	X	X	
Sounding 1 kHz-50MHz	X		
GPR 1kHz-GHz	X	X	
Electomagnetics mHz – 10kHz	X	X	
IP (Resistivity)			X
Magnetics and Gravity	X	X	X
Nuclear Physics			
Neutron	X	X	X
Gamma	X	X	X
Active			X
Seismic			
Acoustic			X
Active			X
Passive			X

Some orbital remote sensing instruments can be used to look for liquid water reservoirs in the crust. The current lack of detection of areas with shallow (>2-3km) reflectors from MARSIS and SHARAD signal the absence of large subsurface water bodies (10s of lateral km). The minimum detection is 10% water in pore space, due to the great difference in dielectric constants. Nondetection means that (1) liquid water is deeper, (2) finely distributed, (3) frozen, or (4) not there at all.

GPR can be used to look for evidence of past life and should be considered a critical instrument to decide optimal drilling locations. By probing the radar stratigraphy at short length scales, the data can elucidate crater stratigraphy, probe depositional environments, and identify potential habitable settings. It can map lateral continuity of layers and reveal the depth of the regolith and the location of the bedrock. Shallow seismic techniques can also look for subsurface water, but can only indicate broad scale stratigraphy and density and are limited to the size of the array.

Geoelectrical techniques can identify shallow subsurface water, especially saline bodies, and minerals such as massive sulfides and hematite.

Nuclear physics techniques, such as active gamma ray radiation, could distinguish what molecule H is in (especially H in water or other phases). Between 60N and 60S, the amount of hydrogen detected indicates >20% by weight mass fraction of water. An orbital collimated instrument would improve current spatial resolution from 50km to 20-30km.

Few of these techniques address chemical information (i.e., they cannot be used to find methane clathrates other than water ice). Most methods look for geophysical properties that distinguish a liquid from a solid.

What is importance of the deep interior? There are two Mars: the early Mars (Noachian 2-400 million) and recent Mars (short periods of clement weather or periodic infusions of volatiles but otherwise dry). You can look at the deep interior to learn about the climate condition at 4 Gya, the most clement period for life on Mars. This is necessary to interpret a chemical record of biosignatures from earliest part of Martian history. Issues to probe include: (a) Interior structure and thermal history, (b) differentiation processes, how materials partitioned themselves in the core, what materials were on the surface, (c) how did the atmosphere get delivered, (d) volatiles and chemicals available, (e) what the magnetic field was like and how long it existed to shield life on the surface, (f) thermal structure and geothermal gradients, and (g) oxidation state of the interior. The recent Mars should also be considered. It can be probed by looking at the climate record in ice.

If we knew when the martian magnetic field (which shields from solar radiation and solar wind sputtering of the atmosphere) collapsed, we could know how long the thick atmosphere existed and how fast did it decay to recent conditions. Paleomagnetic studies might not help much because very little of the early surface record exists, having been modified in the intervening 4 Gya. The size and structure of core and its thermal history can help establish the physics of the dynamo and when it shut down.

Seismic studies can inform us if Mars is tectonically or magmatically active today, especially if the thermal history is known. Three or four stations would be sufficient to triangulate location of seismicity and the possible geothermal activity of recent volcanism.

Is it scientific prudent to capture a sample without drilling? Should return of a surface sample be recommended? If surface carbon that has a high potential to be organic carbon and a geologic context indicative of life is found, that is the preferred sample; otherwise a subsurface sample is warranted.

Session D – Planetary Protection for Both Robotic and Human Exploration

Co-Chairs: Cassie Conley and Gerhard Kminek
Organizer: John Rummel
Rapporteurs: Nina Lanza and Abigail Fraeman

Group D addressed a series of questions, aggregated into five general topical clusters.

What are the planetary protection requirements that should be applied to all Mars missions prior to launch? Are there planetary protection requirements that should apply for all missions, both human and robotic? Should human and robotic missions have different standards? The results of a planetary protection meeting sponsored by ESA and NASA were reported; there it was decided that there should be no distinction between human and robotic missions for planetary protection on Mars, and that future provisions would likely focus on special regions only. Additionally, it was determined that Mars should be divided into zones of allowable contamination levels (forward only).

A question was raised about the definition of "contamination." There are different types of contaminants (human, soil, etc), and each will have a different amount of impact in different martian environments.Trying to separate different contaminants would be difficult, but while it is not possible to eliminate all contaminants, we can control and monitor them. Organics are as important as biotics as sources of contamination, but only biotic contaminants can multiply their initial number. An extreme example can be considered for illustration: what if martian life likes the reduced carbon found in Teflon brought by astronauts? This would cause the biochemistry of the system to change.

Monitoring biotic contaminants poses some unique challenges. The majority of microscopic terrestrial life has likely not been cataloged (the "unknown majority"), making it difficult to identify the source of a biotic contaminant. Even if an unknown microbe were observed, there would be a chance that it is an as-yet unidentified terrestrial rather than a martian entity.

In order to mitigate the risks associated with biotic and organic contamination, it was suggested that an inventory of both biodiversity and organics should be taken for all Mars missions prior to launch. Controls and blanks should also be generated prior to a mission to ensure data quality.

Equal planetary protection requirements should be applied to both human and robotic missions: human spacesuits should not contaminate an area more than a robotic mission. A key difference between mission types was suggested: for robotic missions, all protection mitigation occurs on the front end and is complete by the time the craft reaches Mars, while human missions require constant mitigation. This is not entirely true, however, as rover operations will be influenced by the desire to avoid areas that they are not clean enough to enter. But it does have some merit in helping us think about the complications of human Mars missions.

It was concluded that it is necessary to know the quantity and biodiversity of the bioburden, and to take an organics inventory. The following questions should be evaluated:

- What is on the craft?
- Where is it on the craft?
- What does it do when it gets to Mars?

These requirements will be affected by technical capabilities such as experimental sensitivity, and it is important to keep in mind that terrestrial techniques are about 20 years ahead of techniques used in space instruments.

What are the planetary protection requirements to enable access for Earth vehicles/explorers to Mars special regions? In addition to the requirements set forth above for all missions, special regions should also be identified by the limits on the ability of terrestrial life forms to thrive in those environments. Certain microbes may pose a greater threat to one region than to another, and care must be taken that they do not encounter these places. Thus, depending on the type of special region to be visited, it is conceptually possible (but likely practically impossible) that the craft be sterilized for specific contaminants.

In this discussion, it was emphasized again that it is not possible to prevent contamination, only to mitigate its influence. In terrestrial labs, 10-20% of organisms that are analyzed using current methodology cannot be further identified. This is most often the case when there is a low abundance of these organisms. If these organisms were encountered on Mars, they might appear to be martian but in fact be terrestrial. A single gene index could be developed to uniquely identify terrestrial microbes, though this remains a difficult issue.

For human missions, it was generally agreed that human explorers must be isolated from the martian environment as much as possible, using devices such as positive pressure suits. In addition, the biodiversity inventory for humans is of utmost importance; since there is no way to "sterilize" a human, we must know exactly what has been brought to Mars in order to correctly evaluate what is brought back.

What precursor planetary protection information is required prior to sending humans to Mars, and how should that information be obtained? Environmental conditions on Mars should be well understood before sending humans. This is not only to ensure the safety of the astronauts, but also to ensure that we understand the spread of potential contaminants. Weather and wind patterns should be well understood in order to calculate when and how contaminates will spread. The large global weather patterns on Mars create the possibility that special regions may become contaminated even by missions to non-special areas. Exactly where these contaminates will go and how fast they will travel (1 month to contaminate special regions? 10 years? 100 years?) should be taken in consideration when defining protection guidelines.

Laboratory simulations are an inexpensive way to model the effects of contamination and should be run prior to sending humans to Mars. These simulations can model how Earth organisms will react to the Martian environment. Simulations can also be conducted to understand how potential martian microbes would react to human material. As stated before, these theoretical microorganisms could enjoy consuming the Teflon and rubber in spacecraft and spacesuits, which could cause the behavior of the microbes to change as well as present a risk to missions. Further simulations could be run to predict the change in behavior of the organisms, as well as to understand how to prevent this outcome, e.g., addition of silver to some materials to make them less edible.

There was also a discussion about whether or not a sample return mission was a necessary precursor to a human mission. It was not agreed upon whether or not it should be required; an additional question was whether a single sample from an area would be sufficient to "clear" the area, or if multiple samples are necessary to fully understand the environment. This discussion continues. In any case, sample returns would provide information about the toxicity and reactivity of the martian environment, and could also determine whether harmful, non-terrestrial microbes were present. The location of the human landing might need to be known before samples were acquired.

Participants raised the question of whether it is worth the risk to send humans to Mars at all was raised. Since they undoubtedly will contaminate the planet, is it ethical to send them before knowing more about the biological environment of Mars? This brings up an interesting paradox: we could decide to send humans to Mars only if there is no current martian life, but we may need humans to detect life in the first place.

Should the "special regions" designation be eliminated? Special regions are defined differently today than they were 10 years ago, and they are likely to be defined quite differently 10 years into the future. As more information about Mars is returned, it is inevitable that more regions will be defined as "special." Special regions are likely to have the biggest science return, as well as potential resources. If too many requirements are placed on visiting a special region, we will never go there. Acceptable risk levels were discussed; it was pointed out that on Earth, not all consequences of certain actions are known, but prior to action the risk levels are assessed and agreed upon. It was concluded that the special region designation is here to stay.

How do we establish and track Mars special regions in a cogent and internationally agreeable fashion? An international standard for a Mars GIS system for defining special regions should be created. To do this, standards such as a single martian coordinate system should be developed. All available data sets should be combined in a single GIS, and then special regions could be mapped from these data as they are defined. It was also suggested that algorithms could be developed for defining special regions rather than adding them manually. There was general agreement that an organization should be created as a "keeper of the data" that would keep up to date with evolving definitions of special regions as well as new data from Mars. The PDS is good for archiving and validating data, while the USGS facility in Flagstaff, AZ could assist with setting standards. A COSPAR panel should be generated to ensure international consensus on these evolving standards.

<u>How can compliance with planetary protection protocols be ensured?</u> There was general agreement that education of project leaders and members about the importance and strategies of planetary protection is essential. All members of a mission team must be fully aware of and understand the motives behind planetary protection. This knowledge will ensure that those working on the mission will take the necessary steps to maintain the integrity of the protection process. Lack of attention to required measures by only one or two people has the potential to undermine the entire process. NASA Headquarters should consider creating education requirements related to planetary protection for all mission or project personnel.

Session E – Issues in Mars Sample Return

Co-Chairs: Michel Viso and Noel Hinners
Organizer: Dave Beaty
Rapporteurs: Bethany L. Ehlmann and Victoria Swisher

The group in this breakout session was tasked with examining issues related to Mars Sample Return (MSR), including the nature of a MSR program, the nature of a sample(s), and key technical challenges. Due to the recent announcement of a study on the potential for caching on MSL, substantial discussion also was made on methods, costs and benefits of sample caching. The summary reflects key issues identified by the group. Areas of general agreement are shown in italics.

Sample return: A key programmatic direction. The group was enthusiastic about the reinstitution of planning for Mars Sample Return (MSR). The public support for MSR by the NASA Associate Administrator of the Science Mission Directorate, definition of a time scale, and declaration of sample return as an integral part of the Mars program are particular reasons for optimism. Sample return also contributes as an integral part of the vision to send humans to Mars. It is an exciting and challenging mission that will garner substantial public interest and excitement. (See below, however, for concerns related to the specific nature of MSR and its impact on the rest of the program).

Sample return has been a goal of the Mars science community since the late 1960s. Previous missions, while announced, have not flown, however. Thus, it is worthwhile to examine why these previous incarnations of an MSR mission did not fly and derive lessons from them for preparing for MSR at present. Previous missions

(1) Were not within the funding envelope
(2) Had substantial uncertainty as to the nature of the desired samples and the site(s) from which to obtain them
(3) Faced technical challenges in terms of infrastructure and planetary protection, particularly:
    a. Sample return capsule design
    b. Mars on-orbit rendezvous capability
    c. Sample receiving facility on Earth (BSL-4 class)
    d. Mars ascent vehicle

In recent years, we have largely satisfied (2) as discussed in the next section. The focus of efforts of the community can now be how best to make sample return happen: will we commit to the long-term investment required for #3? Can this be done within acceptable budgetary constraints?

Group E generally felt that it was essential that MSR be part of a larger program of Mars exploration. The previous 10 years of Mars exploration, with multiple discovery-driven pathways has been successful in generating a robust, exciting scientific program. MSR should be a flagship mission within a program of comparable or greater energy and pace of discovery. The group recognized that substantial sustained effort will be necessary to address technological challenges in the years preceding the first MSR mission and this may reduce the number of other near-term opportunities. However, after this investment is made, it is anticipated the first MSR should not be the last MSR. After the first returned samples are evaluated, a set of pathways driven by the resulting science discoveries should dictate additional sample return sites and future landers and orbiters.

Needed technology development and complex mission architecture make MSR a substantial systems engineering challenge and require a long lead time. Thus, appointing a person responsible for achieving the MSR goal and coordinating subprojects to achieve them is a way to sustain the long-term effort. An example of success in successfully surmounting the technological and logistical challenge of sample facility construction is that of the Japanese having nearly finished construction of a receiving facility for potential samples from Hayabusa and subsequent missions. Split mission architecture—a lander/rover to collect samples followed by later landing of a vehicle to launch from Mars, might be desirable. *The scientists and engineers in Group E generally agreed that core MSR technology or telecom-geared missions can and should include "opportunity science".* In addition to the scientific benefit, such missions maintain the energy of the scientific community while preparing for sample return. *The group felt that we need to establish a milestone based technology plan for sample return*. Pre-phase A technology development should be instituted immediately in order to make a 2018 or 2020 launch opportunity. A commitment to and adequate funding for technology milestones aimed at the earliest possible launch could help anchor the mission in a concerted MSR program. Elements of an MSR mission should incorporate collateral science along the way.

It is also realized that sample return would consume substantial resources within the Science Mission Directorate. Several committee members were interested in cooperation to open up other potential funding sources from within NASA and internationally. There was a suggestion to discuss with ESA within the next few months long-term mission planning for MSR in order to establish collaborations and figure into the European budgeting process. *There are also strong linkages between human exploration and MSR in technology development and understanding Mars material*. It was noted that MSR in ESA is part of the Aurora Program. Though it is recognized that NASA's Exploration Systems budget is constrained, given that sample return is a potentially key precursor to human exploration, there was a question as to whether funding from Exploration Systems could be applied to a sample return mission. Samples are needed to understand planetary protection requirements for preventing forward or backward contamination, for understanding the oxidizing properties that are potential health hazards, for developing dust mitigation techniques, and for implications to in situ resource utilization (ISRU). A landing package and sample return launch will feed forward (proof of concept) to landing large human support systems and returning humans to Earth.

Where to go and what to get. There is growing consensus in the Mars community as to the nature of samples needed. The past ten years of Mars exploration have been a great success, bringing us where to we hoped to be: an understanding of the most interesting sites on Mars based on composition as well as morphology. *Hence, potential science from MSR has increased as result of the integrated program of Mars exploration*, especially over the past few launch opportunities (MER, Odyssey, MRO, and ESA's

Mars Express). *In light of new knowledge garnered from orbital and landed missions of the past decade, there is a need to update and detail the science requirements—astrobiological, geological, and atmospheric—for Mars samples*. We know we can get good samples. We have realized *Mars is diverse and thus sample variety is important – grab samples should be a last resort only*. Samples are needed to complement the information that can be achieved from remote sensing alone (e.g. at the Meridiani Opportunity landing site; hematite detected from orbit was only the cap on a massive layer of sulfate-rich siliciclastic sedimentary deposits).

Three questions in particular were considered by Group E:

- <u>Should returned samples be from the subsurface?</u> There was no consensus for this as a demand on a first MSR. This could perhaps be an enhancement for later missions. The nature of the sample (rock type, ice) and astrobiological evidence (carbon, preserved organisms, extant organisms) would dictate the depth. Carbon could potentially be hosted within centimeters of the surface in phyllosilicates and sulfates.

- <u>Does the sample have to be astrobiological?</u> *Do we need to look for bizarre life?* The need for careful definition of science objectives was reiterated. Failure to find evidence for life would certainly not be a mission failure. *Identifying reduced carbon is important and there are substantial questions about climate and geologic history which may be addressed by samples and by dating them.* There are complex technical issues around both organic carbon and dating, and these need detailed study. Looking for "bizarre" life would be a bit ambitious for a first MSR. Once we have returned samples, we will be much better equipped to decide how to search for the unexpected.

- <u>Does sample return require in-situ characterization? How extensive should this be?</u> Two advantages of in-situ characterization were (a) provision of a quality control check of how well we do in-situ science and (b) understanding whether the sample had been altered between its collection on Mars and its analysis on Earth. While the committee recognized these as valuable, there was concern that adding too many complex in-situ analysis requirements would increase mission cost beyond an acceptable envelope. It was generally agreed that, unlike sample return missions such as Genesis or Stardust, we could not simply bring back just any sample. Ideally, *there should be enough on-board analytical equipment to collect a diverse suite of samples of interest, and reasonably preserve these*. However, *the first sample return mission should not be seen as a one-shot, perfection-required opportunity; rather the suite of techniques employed should be improved upon in future sample return opportunities.*

<u>**The potential of caching.**</u> The group spent considerable time discussing the concept of caching of samples for return by a future MSR mission. As sites of key scientific interest will be visited by upcoming landed missions, we have the opportunity to identify samples for which laboratory analysis would be warranted. *Caching is a promising concept but needs detailed assessment of costs and benefits and further precise definition of science*

objectives. The benefit of science goals addressed from the types of samples that could be cached by a particular mission must be balanced against the collection penalty to upstream missions in cost, risk, or operational restrictions. Additionally, *there was general agreement that the program architecture around MSR should include the ability to decide to ignore a cache or decide among caches.* The idea of an intermediate option of identifying, but not collecting, samples for future return was also suggested.

A topic of some concern for all present was the potential add-on of caching capability to MSL. Given the late incorporation of caching on MSL, there are concerns about how well it can be done. Samples on MSL would likely be powdered, and the increased reactivity of a powdered sample would facilitate breakdown of organics and alteration of the sample prior to its opening in a curatorial facility. The lack of a capability to acquire rock pebbles or chips would be seen as a major deficiency. There was concern about how addition of sample caching might cause schedule slip and how an onboard sample might constrain MSL traversing capabilities. In fact, MSL provides a first example of how the tradeoffs between sample acquisition, sample quality and increases in constraints/risks should be assessed in evaluating caching on landed missions.

APPENDIX A

Acronym List

AFL	Astrobiology Field Laboratory
BSL-4	Biosafety Level 4; required for work with dangerous and exotic agents that pose a high individual risk of aerosol-transmitted laboratory infections and life-threatening disease.
COSPAR	Committee on Space Research
ESA	European Space Agency
GIS	Geographic information system
GPR	Ground penetrating radar
Gya	Giga-years (billions of years)
H	Hydrogen
HF	High frequency
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding (instrument flown on the ESA Mars Express mission)
MEPAG	Mars Program Analysis Group
MER	Mars Exploration Rover
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSR	Mars Sample Return
NRC	National Research Council
PDS	Planetary Data System
PLD	Polar Layered Deposit
RAT	Rock Abrasion Tool (carried on the Mars Exploration Rovers)
SAR	Synthetic aperture radar
SHARAD	Shallow Subsurface Radar (instrument flown on MRO)
USGS	United States Geological Survey

APPENDIX B

Final Agenda

COLLOQUIUM ON ASTROBIOLOGY AND MARS EXPLORATION

Pasadena Hilton
168 South Los Robles Avenue
Pasadena, California

Saturday, July 7, 2007

6:00-7:00 pm. Registration (Entrance of the International Ballroom)

Sunday, July 8, 2007

7:30 a.m. Registration will be located at the entrance of the International Ballroom

7:30 a.m. Breakfast for Invited Guests in the California Ballroom

<u>OPEN SESSION (International Ballroom)</u>

8:30 a.m. Welcome and Goals of Colloquium
Michael Meyer, *NASA Science Mission Directorate*

8:35 a.m. Astrobiology and the Exploration of Mars
John D. Rummel, *NASA Science Mission Directorate*

8:50 a.m. Fifty Years of Strategic Planning for the Exploration of Mars
Lennard J. Fisk, *University of Michigan*

9:05 a.m. Exploring Organic Environments in the Solar System
James Ferris, *Rensselaer Polytechnic Institute*

9:40 a.m. The Limits of Organic Life in Planetary Systems
Steven Benner, *Foundation for Applied Molecular Evolution*

10:15 a.m. Break

10:45 a.m. An Astrobiology Strategy for the Exploration of Mars

Bruce Jakosky, *University of Colorado*

11:30 a.m. Planning for Future Mars Missions

Michael Meyer, *NASA Science Mission Directorate*
David Beaty, *Jet Propulsion Laboratory*

12:30 p.m. Lunch for Invited Guests in the California Ballroom

Lunchtime Presentation

ESA's Aurora Program: ExoMars, NEXT and Beyond

Jorge L. Vago, *European Space Agency*

CLOSED SESSION

2:00 p.m. Discussion Groups

Group A: Relationship between MSL, ExoMars, and AFL (Santa Barbara Room)
Jorge Vago, *European Space Agency* (co-chair)
John Grotzinger, *California Institute of Technology* (co-chair)
Michael Meyer, NASA,*Science Mission Directorate* (organizer)

Group B: Scientific Activities for the Human Exploration of Mars (Santa Rosa Room)
Pascale Ehrenfreund, *Leiden Institute of Chemistry* (co-chair)
James Garvin, *NASA, Goddard Space Flight Center* (co-chair)
David H. Smith, National Research Council (organizer)

Group C: Exploration of the Martian Subsurface (Santa Clara Room)
Jeffrey Plaut, *Jet Propulsion Laboratory* (co-chair)
Stephen Gorevan, *Honeybee Robotics* (co-chair, invited)
W. Bruce Banerdt, *Jet Propulsion Laboratory* (organizer)

Group D: Planetary Protection for Robotic and Human Missions (Pasadena Room)
Gerhard Kminek, *European Space Agency* (co-chair)
John Rummel, *NASA Science Mission Directorate* (co-chair)
Katharine Conley, *NASA Science Mission Directorate* (organizer)

Group E: Mars Sample Return (San Marino Room)
Noel Hinners, *Lockheed Martin Astronautics* rtd. (co-chair)
Michel Viso, *CNES* (co-chair)
David Beaty, *Jet Propulsion Laboratory* (organizer)

OPEN SESSION

4:45 p.m. Reconvene for Plenary Session in International Ballroom

5:00 p.m.	Summary reports from Discussion Groups
6:00 p.m.	Adjourn